

## RESEARCH OF AN ADVANCED SEAT BELT SYSTEM

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### Abstract

In the field of collision safety, conspicuous progress has been made in recent years in occupant restraint devices. Collision avoidance technologies are also rapidly developing. Various proposals have been made for next-generation occupant restraint technologies which work in combination with collision avoidance systems. This paper discusses research on a next-generation seat belt system as a first step towards the realization of such a combination.

In this system a DC motor operates in parallel with a conventional pyrotechnic seat belt pretensioner. When a radar sensor system detects a forward obstacle, the DC motor operates to wind the seat belt and reduce slack before collision. This has made the seat belt pretensioner more effective in a front collision. This paper discusses the results of various tests on the motor-seat belt combination, and gives consideration to its effectiveness and shortcomings.

### System Configuration

Figure 1 shows the system configuration of the electric pretensioner seat belt system. A radar sensor employing milli-wave (Figure 2) is located in the front of the vehicle. Figure 3 shows the block diagram of the radar sensor. This radar is FMCW (Frequency Modulated Continuous Wave) type in 77GHz band. The radar unit is composed with a scanning mechanism and electric control circuit.

The radar sensor measures the position, distance and relative velocity of forward obstacles in the direction of vehicle motion. The signal generated by transmitter is sent to a front obstacle from an antenna, and the antenna receives the reflective wave again. Distance with a front obstacle, relative velocity, and a direction are recognized from the phase difference of pulses. Moreover, an antenna is scanned by mechanical scanning mechanism in order to extend the detection range. The possibility of the collision with a front obstacle is judged using the relative information with the forward obstacle and the speed and the operation information of car oneself. Electric Pretensioner is triggered when the possibility is high. This real time data from the radar sensor is brought together with data on vehicle speed, yaw rate, longitudinal acceleration, and the status of steering and braking applied by the driver to comprehensively determine the possibility of collision with a forward obstacle. If the possibility of a collision is judged as high, the radar sensor system triggers operation of the electric pretensioner.

The trigger for the electric pretensioner operation is applied in two stages. The operation flow is in Figure 4. In the first stage, when a forward obstacle has been identified, but steering maneuvers or application of braking can still avoid collision, the electric pretensioner vibrates as it is tightened under a low load. This vibration and tightening alerts the driver to the possibility of collision so that avoidance maneuvers can be commenced. If a high level of risk of collision continues to exist, the system proceeds to

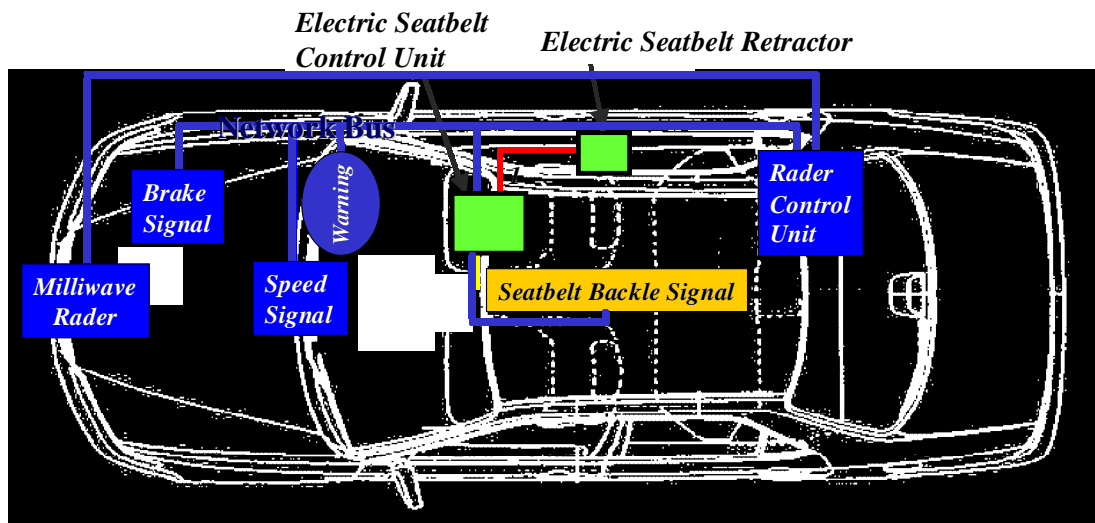


Figure 1. System Feature



Figure 2. Milli-wave Radar

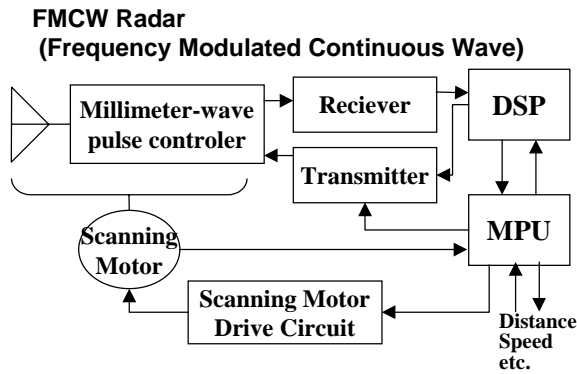


Figure 3. Block Diagram of Radar Sensor

stage two. In the second stage, when collision can no longer be avoided, the seat belt is tightened under a high load to reduce the slack in preparation for collision. This forced tightening of the seat belts can reduce at an early stage the forward displacement of occupants induced by vehicle deceleration before collision when the driver recognizes the danger condition and applies the brakes. After this, on collision, the pyrotechnic seat belt pretensioners are triggered by the conventional crash sensor system to protect the occupants. If it has been possible to avoid collision by steering maneuvers or application of the brakes, the lock mechanism on the electric pretensioner system is released. After fixed time release control of the locking mechanism acts from the time of rewinding control being completed. It acts only in the conditions that G sensor of the seatbelt retractor can be canceled based on a brake signal or a vehicle speed information, and then the locking mechanism of a motor drive system is canceled.

Figure 5. shows the construction of the retractor in the electric pretensioner system. A pyrotechnic pretensioner and a load limiter have been added to a conventional emergency locking retractor (ELR). Operating in parallel with these is a DC motor and a transmission mechanism to transmit motor drive to the ELR shaft. The system has a clutch mechanism to separate the motor drive from conventional seat belt under normal conditions, ensuring that motor drive works is transmitted only when the motor is in operation.

In addition to being operated by the radar sensor, the electric pretensioner system is also operated by brake assist system before an accident.

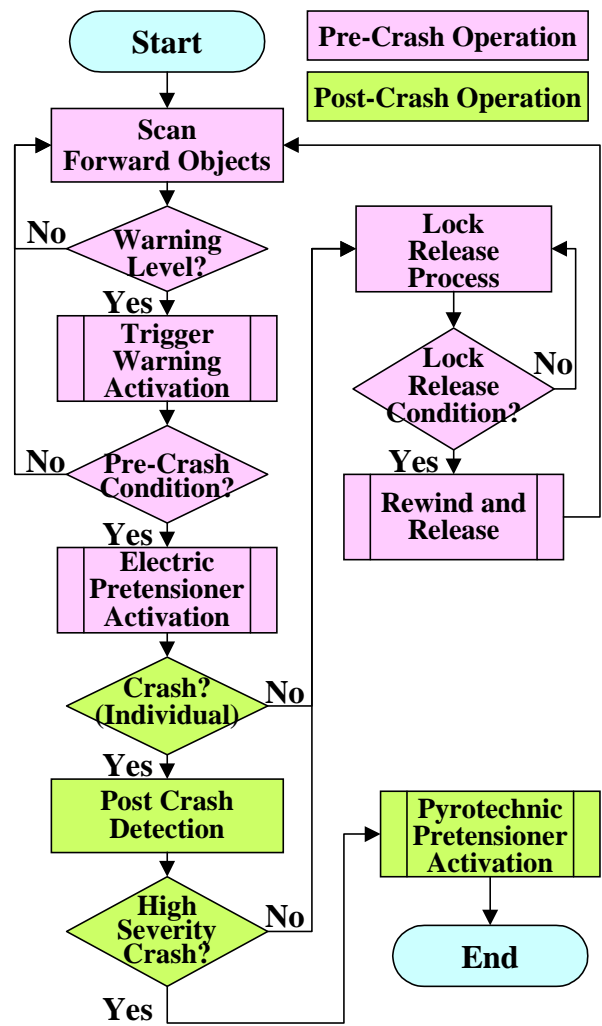


Figure 4. System Control Flow



Pyrotechnic Pretensioner

Motor Drive Unit

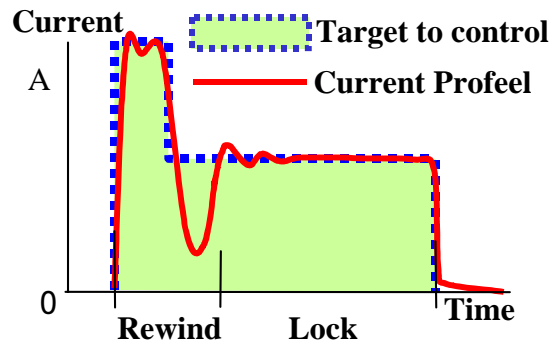
Figure 5. Retractor of Electronic Pretensioner

### Control of Electrical Pretensioner Operation

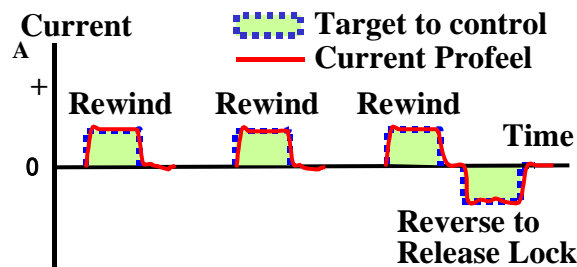
The drive of the electric pretensioner is triggered by the judgement signal from the milli-wave radar. Moreover, when a series of activation are finished, the locking mechanism release sequence of the retractor is performed. The driver of motor controls

### Consideration of Activation from Brake Assist System

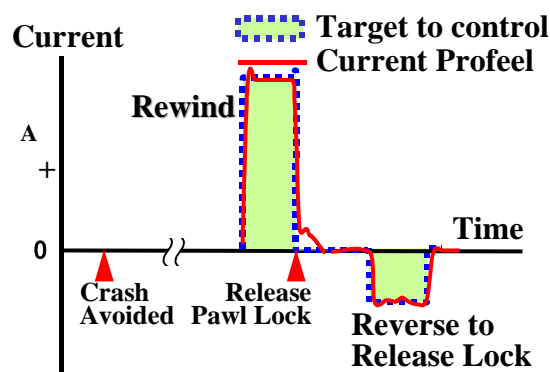
When considering the operation of Electric Pretensioner by brake assistance, the deceleration by braking should be considered in activation of Electric Pretensioner. In the case that the driver finds the front obstacle and applies braking, the locking mechanism of the ELR is worked by the deceleration of the car and adequate load is applied to a seat belt. At this time Electric Pretensioner will be triggered by Brake Assist System which works at the time of sudden braking. The rewinding of Electric Pretensioner should be made faster than the rise of the seat belt load by the deceleration of braking. Figure 9 shows the time history of the pressure of brake cylinder, belt load, and deceleration in the test of sudden braking with the brake assist system and the conventional ELR seat belt. In this test, it takes for 50 milliseconds from starting sudden braking that the brake assist system is triggered. The triggering timing of the brake assist system is set to 0 msec on graph. The pressure of brake cylinder increases further by the operation of Brake Assist System, and the deceleration of car also goes up according to it. On the other hand, the load of a seat belt does not go up, while the locking mechanism of ELR does not work. The load of seat belt goes up when the deceleration reaches around 0.4G and the locking mechanism works after that in around 50 msec, and the slack of the spool of ELR is reduced enough in the around 150 msec. On this condition, the maximum of the deceleration reaches about 1G. Moreover, seat belt load amounts to no less than 40kg. On such conditions for Electric Pretensioner working effectively, it is necessary to complete an operation before seat belt load becomes high. Therefore the electric pretensioner should be complete to work within 100 msec(s) at least as it takes for 20 to 50 millisecond for the trigger Signal to be transmitted from the brake assist system through CAN Network.



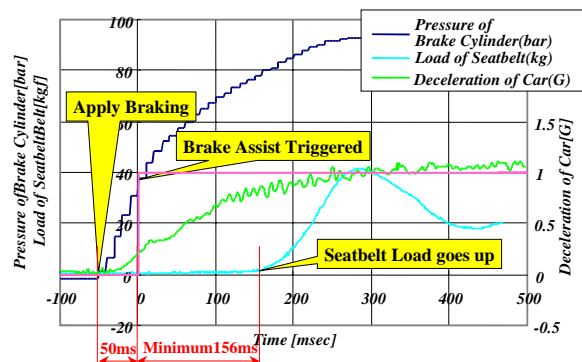
### Figure 6. Control Operation of Pretensioner Activation



### Figure 7. Control Operation of Warning Activation



**Figure 8. Control Operation of Lock Release**



**Figure 9. Braking Test Data with Brake Assist System**

## Results of Performance Tests

### 1. Comparison of forward displacement at Braking before collision

Figure 10 shows a comparison of forward displacement induced in occupant's head by vehicle deceleration when the driver brakes suddenly before a collision with and without the electric pretensioner system in operation. Figure 11 shows a comparison of amount of the seatbelt payout at the test condition. The brakes are suddenly applied at the same time as the existence of an obstacle is recognized, deceleration reaches a maximum of 1G, and the electric pretensioner goes into operation. Comparisons were conducted under the same conditions for occupants classed into four different sizes. For AM95 (adult male 95%tile), AM50 (adult male 50%tile) and AF5 (adult female 95%tile) occupants, the electric pretensioner halved forward displacement in comparison to the conventional seatbelt system. There was no significant difference for occupants using the child restraint system (CRS) because the seat belt was locked before crash by the automatic locking retractor (ALR) with no slack. Comparing these results from the perspective of belt tightening and extension, we see that in comparison to the extension that occurs in the conventional seatbelt, the electric pretensioner remains tightened throughout. In the conventional seat belt, the ELR locking mechanism is not in operation when the vehicle commences deceleration. It is only after deceleration reaches the level preset to trigger locking that the ELR shaft locks. The belt extends in the period between the beginning of initial deceleration and locking. Even after the locking mechanism works, the passenger exerts a load on the seat belt and extends slack wrapped around the shaft of retractor. In the electric pretensioner system, the motor is employed at an early stage to rewind and tighten the belt, and reduces slack of the belt wrapped around the shaft.

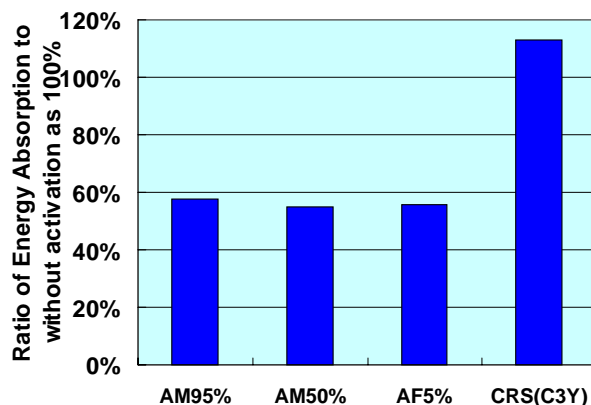


Figure 10. Comparison of Head Displacement at 1G Braking

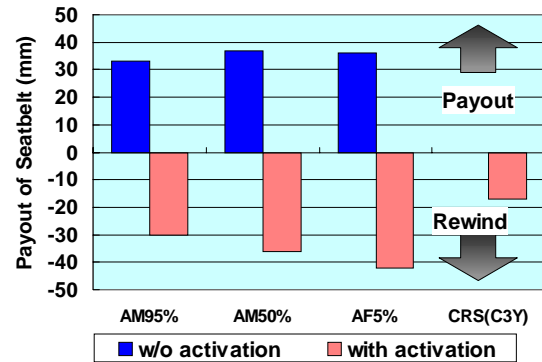


Figure 11. Comparison of Amount of Seatbelt Payout at Hard Braking

### 2. Comparison of performance in frontal barrier test

The performance of occupant protection in crash tests is evaluated with the amount of energy absorption within 75mm of occupant displacement in early stages of a crash test.

Figure 12 shows a comparison of occupant restraint performance with and without the electric pretensioner in operation. Performance comparisons focus on the first half of the collision, because the second half is determined by the characteristics of the load limiter.

In a crash test equivalent to frontal barrier at 55km/h, there was no significant difference in performance for 50%tile and 95%tile occupants. However, a difference in initial restraint performance was observed in tests with 5%tile occupants.

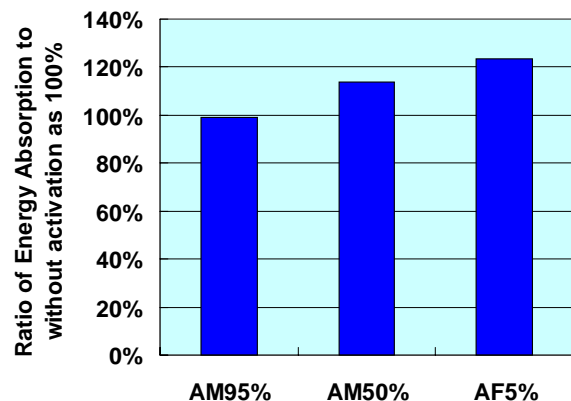


Figure 12. Comparison of the Energy Absorption at Frontal Barrier Crash

### 3. Comparison of performance in offset barrier test

Figure 13 shows a comparison in a crash test equivalent to offset deformable barrier crash at 64km/h. Initial vehicle deceleration is relatively low in offset barrier, it may be hard for operation of the pyrotechnic pretensioner to be fast as compared with full-lap barrier crash. Forward displacement of occupant has already increased to some extent when the pyrotechnic pretensioner activates. The difference in initial restraint performance is due to the fact that tightening of the electric pretensioner before collision controls the forward displacement of the occupant from the initial stages of the crash test.

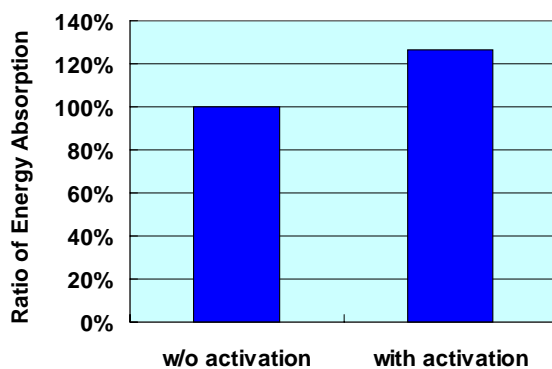


Figure 13. Comparison of the Energy Absorption at Offset Barrier Crash

### 4. Effectiveness of performance with seat belt slack in frontal barrier test

It is generally known that the more slack increases the greater its effect on initial restraint performance in a collision. Frontal crash tests were conducted to compare performance with slack artificially produced by placing urethane foam between the occupant and the seat belt. Tests were first conducted without activation of the electric pretensioner, both with and without seat belt slack. Results demonstrated a relative drop in initial restraint performance with seat belt slack, emphasizing the importance of wearing the seat belt correctly. Further tests showed that the operation of the electric pretensioner was able to considerably reduce the effect of slack. With AF5percentile passengers the equivalent performance was achieved by activation of the electric pretensioner under this test conditions as shown by a normal ELR with no slack. The comparison of those results are shown in Figure 14

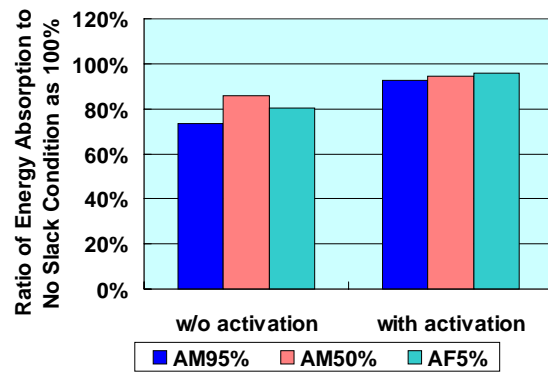


Figure 14. Comparison of the Energy Absorption at Frontal Barrier Crash with 100mm Seatbelt Slack

### Current issues and future development

The results of a series of performance evaluations have demonstrated that the electric pretensioner improves passenger restraint performance in the restricted condition. However, at present the range of operation of the electrical pretensioner system is restricted with respect to the variety of possible collisions. The area covered by current collision prediction sensor system is still narrow, and their capability of detection at close range is limited. In addition, their capacity for collision detection is still limited in comparison to current crash sensor systems, which trigger several types of occupant restraint systems after collision. For instance, they have difficult predicting a collision with a large angle of entry, and, when an oncoming vehicle represents the obstacle, there are cases in which they do not have sufficient resolution to judge whether the obstacle is in their own or the oncoming lane, and judgment takes time.

Future technological advances will make possible high-accuracy detection at a wider range of angles and at close range, enabling the replacement of current crash sensors with a collision prediction system capable of responding to all collision modes.